U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: FUEL TANK FLAMMABILITY MINIMIZATION	**Date:** 4/18/01 **Initiated By:** ANM-112	**AC No:** 25.981-2 **Change:**

1. PURPOSE. This advisory circular (AC) provides information and guidance concerning compliance with the airworthiness standards for transport category airplanes pertaining to minimizing the formation or mitigation of hazards from flammable fuel air mixtures within fuel tanks. This guidance is applicable to transport category airplanes for which a new, amended, or supplemental type certificate is requested.

2. APPLICABILITY.

a. The guidance provided in this document is directed to airplane manufacturers, modifiers, foreign regulatory authorities, and Federal Aviation Administration transport airplane type certification engineers and their designees.

b. This material is neither mandatory nor regulatory in nature, and does not constitute a regulation. It describes acceptable means, but not the only means, for demonstrating compliance with the applicable regulations. The FAA will consider other methods of demonstrating compliance that an applicant may elect to present. Terms such as "shall" and "must" are used only in the sense of ensuring applicability of this particular method of compliance when the acceptable method of compliance described in this document is used. While these guidelines are not mandatory, they are derived from extensive FAA and industry experience in determining compliance with the relevant regulations.

c. This material does not change, create any additional, authorize changes in, or permit deviations from, regulatory requirements.

3. RELATED DOCUMENTS.

a. Title 14, Code of Federal Regulations (14 CFR), Part 25. The applicable sections of 14 CFR part 25 that prescribe the design requirements for the substantiation and certification relating to prevention of ignition sources within the fuel tanks of transport category airplanes include:

§ 25.863 Flammable fluid fire protection
§ 25.901 Installation
§ 25.954 Fuel system lightning protection
§ 25.981 Fuel tank ignition prevention

b. Advisory Circulars (AC). You can obtain any of the following FAA advisory circulars from the U.S. Department of Transportation, Subsequent Distribution Office, SVC-121.23, Ardmore East Business Center, 3341 Q 75th Avenue, Landover, Maryland 20785.

(1) AC 20-53A, Protection of Aircraft Fuel Systems Against Fuel Vapor Ignition Due to Lightning, dated 4/12/85.

(2) AC 25-8, Auxiliary Fuel System Installations, dated 5/2/86.

(3) AC 25.981-1B, Fuel Tank Ignition Source Prevention Guidelines, dated 4/18/01.

c. Society of Automotive Engineers (SAE) Documents. You can obtain any of the following documents from the Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, Pennsylvania 15096.

(1) SAE AIR 5128 "Electrical Bonding of Aircraft Fuel System Plumbing Systems," January 1997.

(2) SAE AIR 4170, "Reticulated Polyurethane Safety Foam Explosion Suppressant Material for Fuel Systems and Dry Bays."

(3) SAE AIR 1903, "Aircraft Inerting Systems" (DRAFT).

(4) SAE AIR 1662, "Minimization of Electrostatic Hazards in Aircraft Fuel Systems," October 1984.

d. Military Specifications.

(1) MIL-B-83054, Baffle and Inerting Material, Aircraft Fuel Tank (March 1984).

NOTE: This reference provides an extensive list of military specifications relating to the use of polyurethane foam.

e. Other Documents.

(1) FAA Document DOT/FAA/AR-98/26, Review of the Flammability Hazard of Jet A Fuel Vapor in Civil Transport Aircraft Fuel Tanks, June 1998. [You can

obtain a copy of this report through the National Technical Information Service (NTIS), Springfield, Virginia 22161, or at the following web site: http://www.fire.tc.faa.gov.]

(2) Aviation Rulemaking Advisory Committee, Fuel Tank Harmonization Working Group, Final Report, July 1998. [You can obtain a copy of this report on-line from the U.S. Department of Transportation (DOT) electronic dockets, Docket No. FAA-1998-4183, at the following web site: http://dms.dot.gov.]

(3) "Effects of Fuel Slosh and Vibration on the Flammability Hazards of Hydrocarbon Turbine Fuels Within Aircraft Fuel Tanks," Technical report AFAPL-TR-70-65 (November 1970), Edwin E. Ott. (Contact Air Force Aero Propulsion Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio.)

(4) FAA Order 8110.34A, "Procedures for the Use of Fuels for Turbine Powered Aircraft," March 1980.

(5) FAA Document DOT/FAA/AR-99/65, "Mass Loading Effects on Fuel Vapor Concentrations in an Aircraft Fuel Tank Ullage." [You can obtain a copy of this report through the National Technical Information Service (NTIS), Springfield, Virginia 22161, or at the following web site: http://www.fire.tc.faa.gov.]

(6) FAA Document DOT/FAA/AR-00/19, "The Cost of Implementing Ground-Based Fuel Tank Inerting in the Commercial Fleet," DOT/FAA/AR-00/19, May 2000. [You can obtain a copy of this report through the National Technical Information Service (NTIS), Springfield, Virginia 22161, or at the following web site: http://www.fire.tc.faa.gov.]

(7) FAA Document DOT/FAA/AR-01/6, "Inerting of a Vented Aircraft Fuel Tank Test Article With Nitrogen Enriched Air," April 2001. [You can obtain a copy of this report through the National Technical Information Service (NTIS), Springfield, Virginia 22161, or at the following web site: http://www.fire.tc.faa.gov.]

(8) "Simulation Modeling and Analysis" by Law and Kelton, 1991.

4. DEFINITIONS.

a. Auxiliary Tanks. Fuel tanks installed which make additional fuel available for increasing the flight range of that airplane. The term "auxiliary" means that the tank is secondary to the airplane's main fuel tanks; i.e., the functions of the main tanks are immediately available and operate without immediate supervision by the flightcrew in the event of failure of inadvertent depletion of fuel in an auxiliary tank. Auxiliary tanks are usually intended to be emptied of usable fuel during flight and have been installed in various locations including center wing structure, horizontal stabilizers, wings and cargo compartments.

b. Flammable. With respect to a fluid or gas, flammable means susceptible to igniting readily or to exploding (14 CFR Part 1, Definitions).

c. Flammability Range. The pressure (i.e., altitude)/temperature domain where the fuel vapor/air mixture is flammable. This domain is dependent on the type of fuel used.

d. Fuel Air Ratio (FAR). The ratio of the weight of fuel vapor to the weight of air in the ullage.

e. Fuel Types. Different fuels are approved for use in turbine powered airplanes. The most widely used fuel types are JET-A/JET-A1 and JET-B (JP-4), per ASTM Specification D1655-99, "Standard Specification for Aviation Turbine Fuels." The approved fuel types for a given airplane type are listed in the Airplane Flight Manual (AFM). Each fuel type has its own properties; those directly related to flammability are "flash point" and "distillation" characteristics. Property differences can occur in a given fuel type because of variations in the properties of the source crude oil and the refining process used to produce the fuel.

f. Inerting. A process where inert gas is introduced into the ullage of a fuel tank so that the oxygen content of the ullage is reduced to a point where ignition and subsequent combustion is precluded. For the purpose of this AC, the tank is considered inert when the oxygen content is less than 10%, when the inert gas is nitrogen.

NOTE: Research in this area is continuing, and the applicant should seek out the latest information on this subject.

g. Lean Fuel Vapor/Air Mixture. A fuel vapor/air mixture that contains a concentration of fuel molecules below that which will support combustion.

h. Lower Flammability Limit. The lower flammability limit (LFL) defines the temperature at a specific altitude, below which the fuel vapor/air mixture is too lean to ignite. For the purpose of this AC, the lower flammability limit is considered equal to 10°F below the fuel flash point (FP), as determined by the American Society for Testing and Materials standard, D56-98a, "Standard Test Method for Flash Point by Tag Closed Tester;" and corrected for altitude by -1°F per 808 ft. altitude increase from sea level. Alternatively, the LFL may be expressed in terms of Fuel Air Ratio (FAR) as FAR=.032 at sea level, increasing linearly to .043 at 60,000 ft. Where minor differences occur in these two definitions, the FAR definition will take precedence.

i. Operational Time. For the purpose of this AC, the time from the start of preparing the airplane for flight (that is, turning on the auxiliary power unit (APU)/ground power, starting the environmental control systems, etc.), through the actual flight and landing, and through the time to disembark any payload, passengers, and crew.

j. Rich Fuel Vapor/Air Mixture. A fuel vapor/air mixture that contains a concentration of fuel molecules above that which will support combustion.

k. Ullage, or Ullage Space. The volume within the tank not occupied by liquid fuel.

l. Unheated Wing Tank. A conventional aluminum structure, integral tank of a subsonic transport wing, with minimum heat input from aircraft systems or other fuel tanks that are heated.

m. Upper Flammability Limit. The upper flammability limit (UFL) defines the temperature at a specific altitude, above which the fuel vapor/air mixture is too rich to ignite. For the purpose of this AC, the upper flammability limit is considered equal to the fuel flash point +62.5°F, and corrected for altitude by -1°F per 512 ft.-altitude increase. Alternatively, the UFL may be expressed in terms of Fuel Air Ratio (FAR) as a FAR=0.24 at sea level, decreasing linearly to 0.142 at 60,000 ft. Where minor differences occur in these two definitions, the FAR definition will take precedence.

> **NOTE:** FAA Document DOT/FAA/AR-98/26 provides further information on this subject. The FAA has developed an Excel© spreadsheet to calculate the FAR for Jet-A and Jet-A1 fuels. This document is available from the FAA Technical Center, web site address: http://www.fire.tc.faa.gov.

5. REGULATORY BACKGROUND.

a. Amendment 25-11 to part 25 introduced the requirements of § 25.981 pertaining to limiting temperatures in fuel tanks so as to prevent ignition of fuel vapors in the fuel tanks from hot surfaces. Advisory Circular 25.981-1A, published in 1972, provided guidance that included failure modes that should be considered when determining compliance with the fuel tank temperature requirements defined in § 25.981.

b. Other sections of part 25 require prevention of ignition sources from lightning (§ 25.954) and from failures in the fuel tank system (e.g., §§ 25.901 and 25.1309). Sections 25.901 and 25.1309 describe the provisions to evaluate the fuel tank system and to show that "no single failure or malfunction or probable combination of failures will jeopardize the safe operation of the airplane . . .." However, service history has shown that ignition sources have developed in airplane fuel tanks due to external ignition sources, and internal ignition sources resulting from unforeseen failure modes or factors that were not considered at the time of the original certification of the airplane.

c. Section 25.981, as amended by Amendment 25-102, was adopted to provide improved standards for:

- preventing ignition sources within fuel tanks, and
- minimizing the exposure to operation of transport airplanes with flammable vapors in the fuel tanks.

(1) Under Amendment 25-102, the title of § 25.981 was revised to "Fuel tank ignition prevention," and paragraphs (a) and (b) were revised to address the prevention of ignition sources within the fuel tanks. Guidance regarding these paragraphs is provided in AC 25.981-1B, Fuel Tank Ignition Source Prevention Guidelines.

(2) Amendment 25-102 also added a new paragraph (c), which requires minimization of the formation of flammable vapors in the fuel tanks, or mitigation of any hazards if ignition does occur. Paragraph 25.981(c) is intended to promote design practices that reduce exposure to operation with flammable vapors in transport airplane fuel tanks to the lowest practical level. That paragraph reads as follows:

> ***§ 25.981(c)*** *The fuel tank installation must include:*
>
> *(1) Means to minimize the development of flammable vapors in the fuel tanks* (in the context of this rule, "minimize" means to incorporate practicable design methods to reduce the likelihood of flammable vapors)*, or*
>
> *(2) Means to mitigate the effects of an ignition of fuel vapors within fuel tanks such that no damage caused by an ignition will prevent continued safe flight and landing.*

d. The changes to § 25.981 adopted by Amendment 25-102 are not intended to require prevention of the development of flammable vapors in fuel tanks. Methods that could completely prevent the development of flammable vapors in fuel tanks, such as full-time fuel tank inerting used on some U.S. military vehicles, have not been considered to be practical for use on commercial airplanes (see the document referenced in paragraph 3e (2) of this AC). Rather, the regulation is intended to preclude the use of design methods that are likely to result in flammable vapors developing in fuel tanks, when other practical design methods are available that can reduce the likelihood of such development such as the selective use of inerting to reduce flammability exposure. (The Aviation Rulemaking Advisory Committee is reevaluating fuel tank inerting methods that could eliminate or further reduce development of flammable vapors in transport airplane fuel tanks. The report is due to the FAA in July 2001.)

(1) For example, the regulation does not prohibit installation of fuel tanks in the cargo compartment, placing heat exchangers in fuel tanks, or locating a fuel tank in the center wing. The regulation does, however, require that practical means, such as transferring heat from the fuel tank (via the use of ventilation or cooling air), be incorporated into the airplane design:

- if heat sources were placed in or near the fuel tanks that significantly increased the formation of flammable fuel vapors in the tank, or
- if the tank is located in an area of the airplane where little or no cooling occurs.

(2) Selective use of inerting, either on the ground or in flight can also be used, particularly if fuel tank flammability is significantly higher in one particular fuel tank or phase of flight.

(3) The intent of the regulation is to require that the exposure to formation or presence of flammable vapors is equivalent to that of an unheated wing tank in the transport airplane being evaluated. This may require incorporating design features to minimize the formation of flammable vapors, or means to mitigate the hazards, assuming that ignition does occur in fuel tanks, such as those located in the center wing box, horizontal stabilizer, cargo compartment, or other pressurized areas of the airplane.

e. This AC describes acceptable methods for minimizing the exposure of fuel tanks to flammable vapors. It discusses the installation of fire suppressing polyurethane foam as an explosion suppression means that may be used in lieu of reducing flammability exposure.

6. <u>DEMONSTRATING COMPLIANCE WITH THE REGULATIONS</u>.

a. Section 25.981(c) provides two options for addressing the hazards associated with fuel tank flammability:

- minimizing fuel tank flammability, and
- mitigating the hazards if ignition of the fuel vapors occurs.

b. The following sections of this AC discuss various critical design issues that applicants must consider when developing certification plans for using either of these options.

7. <u>MINIMIZING FUEL TANK FLAMMABILITY</u>. The critical considerations in minimizing exposure to operation with flammable mixtures in the tank include the control of oxygen concentration and/or the formation of flammable vapors. Factors influencing the formation of flammable vapors include fuel type, fuel temperature, and any design feature that increases the potential for fuel mists to be created. Design practices that reduce or eliminate the overall flammability risk are described below. Airplane designs submitted for FAA evaluation will be evaluated against these practices. Because the intent of the regulation is to limit the exposure of fuel tanks to flammable fuel vapor/air mixtures to a small amount of the operational time for that airplane type, the applicant should take practical design precautions, as discussed within this AC.

a. <u>Oxygen Concentration</u>. Fuel tank inerting is a highly effective means of reducing or eliminating the flammability exposure within a given tank. This method eliminates flammable vapors by displacing oxygen from the ullage space of the tank with inert gas. The military has used this method to prevent fuel tank explosions in combat airplanes. The development of nitrogen gas separation technology has allowed the size and weight of nitrogen inerting systems to be significantly reduced. (The Aviation Rulemaking Advisory Committee is reevaluating fuel tank inerting methods that could eliminate or further reduce development of flammable vapors in transport airplane fuel tanks. The report is due to the FAA in July 2001.)

(1) Oxygen Level. The accepted level for tank inerting used by the military is to reduce the oxygen concentration in the tank ullage to less than 9%. The oxygen concentration needed to prevent a catastrophic fuel tank rupture in commercial applications may vary by tank design during an ignition event. The higher the oxygen concentration, the higher the pressure that is developed in the fuel tank. Therefore, the applicant may establish the acceptable oxygen concentration based up evaluation of the structural capability and maximum peak pressure of the fuel tank. An oxygen concentration of 10% or less by volume is acceptable for transport airplane fuel tanks inerted with nitrogen, without additional substantiation.

(a) The applicant may show that inerting is only needed for certain missions or parts of a mission to bring the tank fuel vapor/air mixture average exposure down to an acceptable level. Inerting may be achieved by supplying inert gas from:

- on-board storage bottles holding either gas or liquid inerting agent,
- on board inert gas generation systems (OBIGGS), or
- a ground storage system if the tank is inerted only on the ground.

(b) Nitrogen is currently the inert gas of choice for inerting fuel tanks, since it is inexpensive and has minimal undesirable effects on the fuel system and engines. Use of other gases, such as carbon dioxide is another option. Certification of systems using gases other than nitrogen will require the applicant to develop a certification plan to address any unique considerations, such as absorption of the gas by the fuel and the effect of the absorbed gas on fuel system performance, which would be a concern with the use of CO_2 as an inerting agent.

(c) Fuel loaded on the airplane from sources vented to atmosphere contains dissolved oxygen. The applicant should consider the effect of oxygen that may rapidly evolve from the fuel when pressure in the tank is reduced, such as during climb, when determining the fuel tank flammability. (Note: An FAA ground and flight test program evaluated the effectiveness of inerting a center wing fuel tank with a ground based nitrogen enriched air supply without a closed vent system. The testing included measuring the effects of oxygen evolution. The results of the test program will be contained in a report that is expected to be published in July 2001.)

(2) Compliance Demonstration. Flight test demonstration and analysis will be required to demonstrate the effectiveness of an inerting system. The demonstration should include critical conditions and demonstration that the inerting system reduces the

oxygen concentration in the tank to an acceptable level, without leaving pockets of oxygen concentrations above the maximum level within the tank.

(a) When the applicant uses inerting as one part of an overall method to reduce flammability (for example, inerting in combination with tank temperature control), the applicant should demonstrate the effectiveness of each part of the method independently, as well as in normal operation.

(b) In addition, the applicant must substantiate that the added system meets the installation requirements of part 25. For example, installation of an inerting system may require the fuel tank vent system to be closed to outside atmosphere in order to maintain a slightly positive pressure and maintain the effectiveness of the inerting system. The fuel tank vent system would be required to meet the applicable requirements of subpart E of part 25. (Note: An FAA ground and flight test program evaluated the effectiveness of inerting a center wing fuel tank with a ground based nitrogen enriched air supply without a closed vent system. The results of the test program will be contained in a report that is expected to be published in July 2001.)

(3) System Reliability Considerations. Inerting systems are considered an added level of protection above that provided by design features incorporated to prevent ignition sources in fuel tanks. Therefore, the system is not considered flight critical, and airplanes may be dispatched with the system inoperative for short periods of time, provided the overall exposure to flammable vapors, including dispatch with the system inoperative, meets the flammability requirements of § 25.981(c).

(4) Indications. Inerting systems are considered a “safety enhancing” system and would not be considered an “essential” system. Therefore, no inflight indication to the flightcrew or any associated flightcrew procedures would be needed for enroute failure of the inerting system. Appropriate limitations on operation with inoperative equipment should be placed in the MMEL. For example, appropriate level messages that are consistent with any dispatch provisions of the MMEL should be provided if a nitrogen inerting system is not functioning properly.

(5) Inerting System Safety Considerations. Fuel tanks that use nitrogen inerting require special maintenance procedures. Maintenance actions that require entry into a fuel tank that contains inert gas may be hazardous if appropriate safety precautions are not followed. The fuel tank should be ventilated and an appropriate air source provided. Appropriate warning information should be included in the Maintenance Manuals, and placards should be placed at fuel tank entry points to warn maintenance personnel of any hazards associated with maintenance actions or tank entry.

b. Formation of Flammable Vapors.

(1) Misting and sloshing.

(a) The flammability of fuel vapors in a fuel tank can be dramatically influenced by agitation, sloshing, or misting of fuel, which results in a higher concentration of fuel molecules in the ullage space. Applicants should incorporate in the design those design practices that reduce the potential for fuel agitation, sloshing, and misting so that flammability is minimized. Examples of proven design practices include:

- installation of sufficient baffling in the tanks to reduce sloshing,
- returning any fuel used to cool fuel pumps to the bottom of the tank,
- introducing fuel during refueling at the bottom of the fuel tank through low velocity nozzles.

(b) Section 6 of SAE Document AIR 1662 describes recommended design practices for minimizing hazards associated with electrostatic charging in fuel tanks. Several of these practices relate to minimizing the formation of flammable vapors, including:

- Introducing fuel at low velocity near the bottom of fuel tanks, directing it to flow on a grounded conducting surface;
- Using a balanced distribution system to insure that all fuel tank bays are filled to equal levels to assist in reducing fuel velocity (this maximizes relaxation time and minimizes mist formation); and
- Using special precautions (reference paragraph 3e (5) of this AC) when switching from low vapor pressure to high vapor pressure fuels. During “switch” loading, the fuel/air ratio in the ullage is almost certain to pass through the point of minimum ignition energy. These practices greatly reduce the presence of fuel mist that will broaden the flammability range of the fuel at the lean end and cause flammable vapors at temperatures well below the flash point.

(2) Fuel Types.

(a) The flash point of the fuels proposed for each application should be carefully evaluated. Use of any low flash point fuels, such as JP-4 (and other fuels such as Russian or Chinese fuels) must be analyzed if they are proposed for use as an approved fuel. Use of JP-4 type fuels on a typical transport airplane may significantly increase operational exposure to flammable vapors. Therefore, other minimization means, such as inerting, may be required to mitigate the exposure created by continuous use of such fuels.

(b) Applicants may propose limited use of such fuels for ferry flights or for limited passenger-carrying operations, similar to operations under the Master Minimum Equipment List (MMEL). Appropriate limitations may be placed in the Airplane Flight Manual to address this issue.

(3) Fuel Tank Temperature. On any one airplane type, the most effective methods for controlling fuel tank temperature may vary between different fuel tanks, according to their exposure to the risk. For instance, fuel tanks located in the wings of subsonic transport airplanes, with little or no heat input from airplane systems or from other adjacent fuel tanks, have been analyzed and shown to meet the intent of the regulation; whereas, fuel tanks located within the fuselage contours require more design attention. Additionally, auxiliary fuel tanks located in the cargo compartment or pressurized areas, tanks located in the center wing box, and horizontal stabilizer tanks may have less ability to reject heat to ambient air, both on the ground and in flight. These tanks may be subject to heat sources from equipment located nearby in the fuselage, such as the air conditioning packs that supply cool air to the cabin. For fuel tanks that, because of installation location or other factors, do not minimize the exposure to operation with flammable vapors, the applicant should provide other means of addressing the safety objectives of § 25.981(c). The following are examples of design solutions that may be proposed:

(a) Managing Heat Transfer to the Fuel Tank.

1 In general, heat sources should not be located near fuel tanks. Additionally, heating from other sources, such as hydraulic heat exchangers or rejection of heat from engine systems, should be prohibited unless features are incorporated to maintain fuel tank flammability equivalent to an unheated wing fuel tank.

2 Locating heat-producing systems away from the tanks should be considered. If this is not a practical solution, the applicant should address controlling heat transfer to the fuel tank. Possible technical solutions include:

- the use of thermal insulation blankets, and/or :
- providing ventilation or dedicated cooling to remove excess heat from areas adjacent to the tank.

(b) Cooling/Ventilation of Fuel Tanks.

1 Some auxiliary fuel tanks are located in areas of the airplane where little or no cooling occurs, such as:

- the center wing box,
- horizontal stabilizer box, or
- fuel tanks located in the cargo compartment

For these tanks, ventilation or dedicated cooling may be an effective means of demonstrating compliance. The cooling/ventilation means should be effective under all operating conditions (including ground and flight operation) that are considered necessary to achieve the desired goal of showing the tank flammability is equivalent to the unheated wing tanks.

2 Adequate cooling/ventilation of the tank may be provided for certain airplane types by means such as:

- installing an air gap in spaces adjacent to fuel tanks and using a fan during ground operation;
- using ram air inlets for in-flight operation to transfer heat from the tank; and
- bleeding cool air from the environmental control system (ECS) packs into the air gap.

3 Some auxiliary fuel tank installations have been designed to use cabin air pressure vented into the tank as a means of transferring fuel from the fuel tank. Venting of air through the tank after fuel is transferred, so that a lean fuel air mixture results, may be an effective means of reducing flammability. If this approach is used, the applicant should consider the criteria and guidance provided in paragraph 7b(4), Fuel Tank Ullage Sweeping, of this AC.

4 One means of maintaining a lean mixture may be venting air from the transfer system air source though the empty tank. If this approach is used, the applicant should consider the criteria and guidance provided in paragraph 7b(4), Fuel Tank Ullage Sweeping, of this AC.

(c) Acceptable Means of Determining the Flammability Exposure of a Given Tank.

1 The temperature of the fuel in the fuel tanks heavily influences fuel tank flammability. Integral aluminum fuel tanks located in the wing, fueled with Jet A fuel, operated on typical flight profiles, and not heated by airplane heat sources are considered to be acceptable with respect to minimizing the formation of flammable fuel vapors.

2 One method of demonstrating equivalence to unheated wing tanks is discussed in Appendix 1 to this AC. This method is based on development of a validated fuel tank thermal model for both an unheated wing tank and the tank of interest. An analysis of the fleet operation of the airplane type is also developed to show that overall exposure of the fleet to flammability is equivalent to the unheated wing tank. In this case, the fuel temperature of the tank of interest may not be equivalent to an unheated wing fuel tank under all conditions. Temperature control may be used to

regulate the flammability so that overall flammability exposure is shown to be equivalent to the unheated wing fuel tank.

3 Any subsonic transport airplane equipped with only wing fuel tanks, and that is designed in accordance with the design guidelines identified in paragraphs 7b(1), (2), and (3) of this AC, would be considered to meet the intent of the rule without further evaluation. If the tank of interest is not shown to have equivalent exposure as the unheated wing tank, the applicant should consider alternative means to reduce flammability or to mitigate the effect of an ignition in the tank, as described in the following paragraphs.

(4) Fuel Tank Ullage Sweeping. A positive ventilation system may be used to "sweep" the ullage of flammable fuel vapor/air mixtures at a rate that keeps the ullage lean in spite of a higher-than-desirable fuel temperature. This ventilation system may be used as needed to satisfy the requirement of the regulation, but should address any negative effects, such as sweeping unburned hydrocarbons into the atmosphere. The applicant should demonstrate that the ullage sweeping system does not leave pockets of flammable fuel vapor/air mixtures within the tank.

(5) Higher Flash Point Fuels. One method of minimizing the exposure to operation with flammable fuel vapors is to restrict the fuel type specified in the Airplane Flight Manual to higher flash point fuels (e.g., JP-5 fuel, which has a flash point of 140 F). This method, in combination with other means, may be effective at reducing the exposure. However, as discussed in the ARAC Fuel Tank Harmonization Working Group Report (reference paragraph 3e(2) of this AC), this approach is not considered practical at this time.

8. MITIGATING HAZARDS IF IGNITION OF THE FUEL VAPORS OCCURS.

a. An alternative to satisfying the requirements of § 25.981(c)(1) is to satisfy the requirements of § 25.981(c)(2). A means may be provided to protect a tank from structural and systems damage that could prevent continued safe flight and landing of the airplane. This alternative recognizes that an applicant may choose to accept a high flammability exposure in a given tank and to provide additional protection to extinguish or suppress an explosion in a tank if an ignition occurs.

b. The U.S. Air Force and other military forces have demonstrated the effectiveness of using appropriate foams to fill the fuel tank and thereby control the pressure rise following an ignition of the fuel vapor/air mixture. This method is in use on several types of airplane. The applicant may use such a foam installation to satisfy the requirements of § 25.981(c)(2). The applicant should demonstrate that the foam type is effective in suppressing explosions to a level where structural and system damage is prevented. Additionally, the applicant should:

(1) Provide data on the foam, including material, pore size, and intended method for installing the foam in the tank.

(2) Address the potential for, and the effects of, degradation of the foam, from any environmental effects and long term aging, on both the airplane and engine fuel systems.

(3) Address the effects of the foam installation on fuel system performance, including:

- engine feed,
- venting,
- unusable fuel,
- sump capacity,
- expansion space capacity,
- fueling, and
- defueling, and
- the effect of the foam on electrostatic buildup in the tank.

(4) Address the effect of the foam installation on the airplane fuel system, as well as the APU and engine fuel systems. Additionally, the applicant should develop maintenance procedures to ensure the foam is correctly installed, both initially and when reinstalled, if removed for access to the tank.

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APPENDIX 1

VALIDATED FUEL TANK MODEL

1. This analytical method provides a means to assess the degree of flammability of an unheated wing tank in the airplane of interest and to show that the exposure to operation with flammable vapors in the tank of interest has been minimized to that level. It is based on predicting the average fleet exposure to operation with flammable fuel air vapors in the fuel tank. The average exposure is calculated for the specific fleet of airplanes of interest for which approval is sought. This method requires the development of a thermal model for the unheated wing tanks and the tank of interest of a given airplane type, followed by a comparative analysis that considers factors that influence the fuel tank flammability. Factors that must be considered include fuel properties, mission length, fuel management, worldwide ambient temperature distribution, etc.

2. The presence of flammable vapors should be determined independently for each tank. Within each tank where barriers or walls prevent mixing of the fuel/air mixtures, separate volumes should be treated independently to determine the worst case exposure for that tank. The analysis should take into account all fuel types for which certification is sought, and the expected frequency of use for each fuel type.

3. To ensure that a consistent method and assumptions are used in this process, the following guidelines are provided.

a. <u>A Monte-Carlo analysis</u> (ref. paragraph 3(e)(8) of this AC) of the tank in question should be conducted to show that the tank has a flammability exposure equivalent to unheated wing tanks over the expected range of operational conditions and fuel types. The Monte Carlo simulation calculates values for the parameter of interest by randomly selecting values for each of the uncertain variables from distribution tables. This calculation is conducted over and over to simulate a process where the variables are random within defined distributions. The results of a large number of cases can then be used to approximate the results of the real world conditions. This method uses five important analysis techniques and databases for fuel tank simulation:

(1) A validated computer simulation of the thermal behavior of the tank in question is developed to evaluate conditions likely to be encountered during the operational flight profile of the airplane of interest.

(2) A statistical distribution of mission durations expected for the airplane model worldwide is developed.

(3) A statistical distribution of ground and cruise temperatures likely to be experienced worldwide is used.

(4) A statistical distribution of likely fuel types, and properties of those fuels, expected to be seen worldwide is used.

(5) A definition of the conditions when the tank in question will be considered flammable is used.

b. <u>Items (1) and (2) above</u> should be created by the applicant. The applicant should present the rationale and validation data to justify the items.

(1) Item 1, Computer Simulation.

(a) Item 1 requires that an applicant create a computer model that can randomly select the following conditions:

- the ambient temperature at the airport of departure;
- the ambient temperature at cruise altitude;
- the flash point variability of the fuel type loaded; and
- the mission duration.

(b) Using the randomly selected input conditions, the applicant can calculate the temperature of the fuel in the tank(s) in question along the mission profile. The applicant may also choose to calculate the Fuel Air Ratio (FAR) of the tank ullage along the mission profile. From this data, the applicant can calculate the time the tank(s) are flammable, relative to the total mission duration. As noted above, the effectiveness of any inerting system can be included in this analysis.

(c) By repeating this process several hundreds of times, a fleet average flammability exposure, expressed as a percentage of the total operational time, can be calculated. The minimum number of cases to be run for this method should be 1,000 cases.

(d) The applicant should also conduct the same analysis for an unheated wing tank (as defined in paragraph 4, DEFINITIONS, of this AC) of the same model airplane as a baseline level of flammability. By comparing the baseline flammability on an unheated wing tank to the tank in question, the applicant can demonstrate that adequate provisions have been included in the design to minimize flammability exposure.

(2) Item 2, Statistical Distribution of Mission Durations. The Item 2 mission duration should include ground operational time when the airplane systems (such as air-conditioning packs and other heat producing devices) are operating, unless limitations against use are placed on the airplane. The analyses should assume that:

(a) For short flights (less than 25% of the airplane's maximum endurance with a 75% payload), the preflight ground operational time should be 30 minutes.

(b) For medium duration missions (between 25% and 60% of the airplane's maximum endurance with a 75% payload), the preflight ground operational time should be 45 minutes.

(c) For long duration missions (over 60% of the airplane's maximum duration with a 75% payload), the preflight ground operational time shall be 90 minutes.

c. Items 3, 4, and 5 are beyond the control of the applicant. To avoid confusion and provide standardization for all applicants, the following conditions are provided and should be used in the analyses to show compliance with the regulation, unless the applicant provides compelling information that would permit the use of alternatives.

(1) Item 3, Ground and Cruise Temperatures.

(a) The mean ground ambient temperature should be assumed to be 59°F, with a one-sigma value of 30°F.

(b) The mean isothermal temperature (atmosphere above tropopause where constant temperature occurs) used in the analysis should be -70°F, with a ± one sigma value of 8°F. Interpolation between the ground and isothermal temperatures should be according to the following:

1 For ground ambient temperatures at or above 40°F, the ground ambient temperature should lapse at a rate of -3.57°F per 1,000 ft., until the cruise temperature calculated for that flight is reached. Above that altitude, the temperature should be constant.

2 For ground ambient temperatures colder than 40°F, the temperature should vary linearly with altitude to a temperature of 4.35°F at 10,000 ft. and then lapse linearly at a rate of -3.57°F per 1,000 ft. to intercept the cruise temperature calculated for that flight. Above that altitude, the temperature should remain fixed at the cruise temperature.

(2) Item 4, Fuel Types.

(a) Jet-A and Jet-A1 fuel should be assumed to have a mean value of the flash point of 120°F, and a one-sigma variation of 8°F.

(b) Jet-B/JP-4 fuels should be assumed to be substantially limited in use (less than 0.5% of missions) or not approved for use on the airplane type under evaluation. Limits on the use of these fuels should be controlled by the AFM, as discussed in paragraph 7b(2) of this AC. An applicant proposing to use Jet-B/JP-4 type fuels to a greater extent than the limited use defined above should define the expected usage, and assume the mean value of the flash point of Jet-B to be -20°F, with a one sigma value of 5°F.

(3) Item 5, Flammable Conditions.

(a) The upper and lower flammability limits should be as defined in paragraphs 4g and 4h of this AC. An example of plotted flammability limits is shown in Figure 1.

(b) An applicant electing to include the effect of reduced fuel quantity on FAR in this method should use the reduction correction shown in Figure 2.

(c) An applicant electing to use FAR as a measure of flammability in this method should use the FAR limits versus altitude shown in Figure 3.

(d) The applicant may include in the analysis the effect of the response time to build up or reduce FAR as pressure and temperature changes. The response rate varies with the volume of fuel in the tank, and should be established for the condition of interest. For example, the exponential response rate and the time constant should be defined, with substantiating data, for both increasing FAR and reducing FAR for a range of fuel tank quantities.

(e) The applicant may include in this analysis the effect of any inerting system. The applicant should present a description of the system, including its control logic, and data to substantiate its performance when lowering the ullage oxygen content to below 10% and maintaining the level below 10%. Where the system is a "one shot" design, the applicant should address degradation of the ullage inerting level with:

- time,
- altitude,
- fuel out-gassing,
- air inhalation with fuel use or altitude reduction, and
- the possible effects from vent system operation.

4. Compliance Report. The compliance report should include the results of the analysis described above, including substantiating data for the assumptions used in the analysis, and test data validating the thermal analysis used. The applicant should also present an analysis of a real or hypothetical unheated wing tank on the same airplane. The tank in question will be considered to have an acceptably low flammability exposure if it is equal to or less than the unheated wing tank.

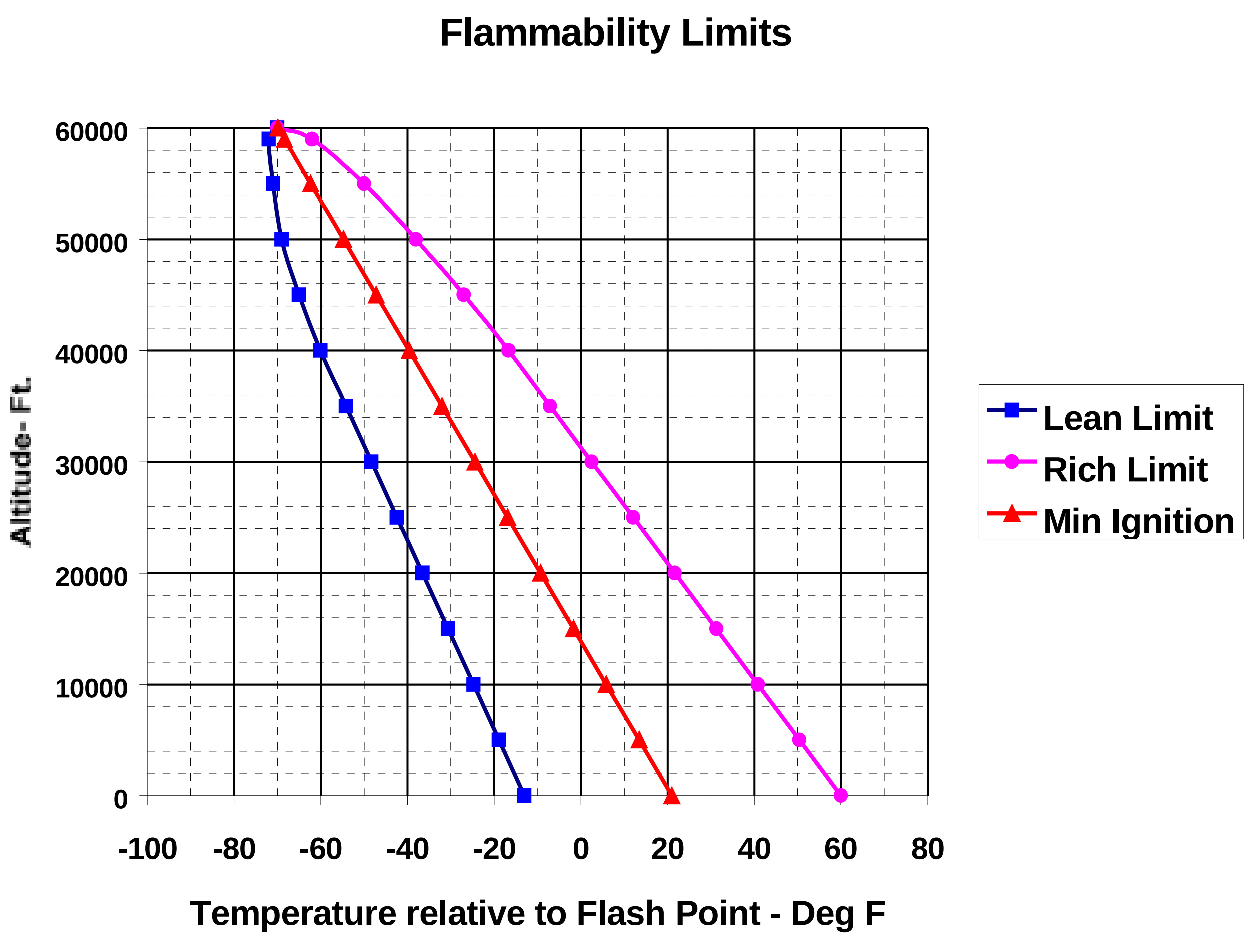

Figure 1: Fuel Flammability Range as a Function of Altitude

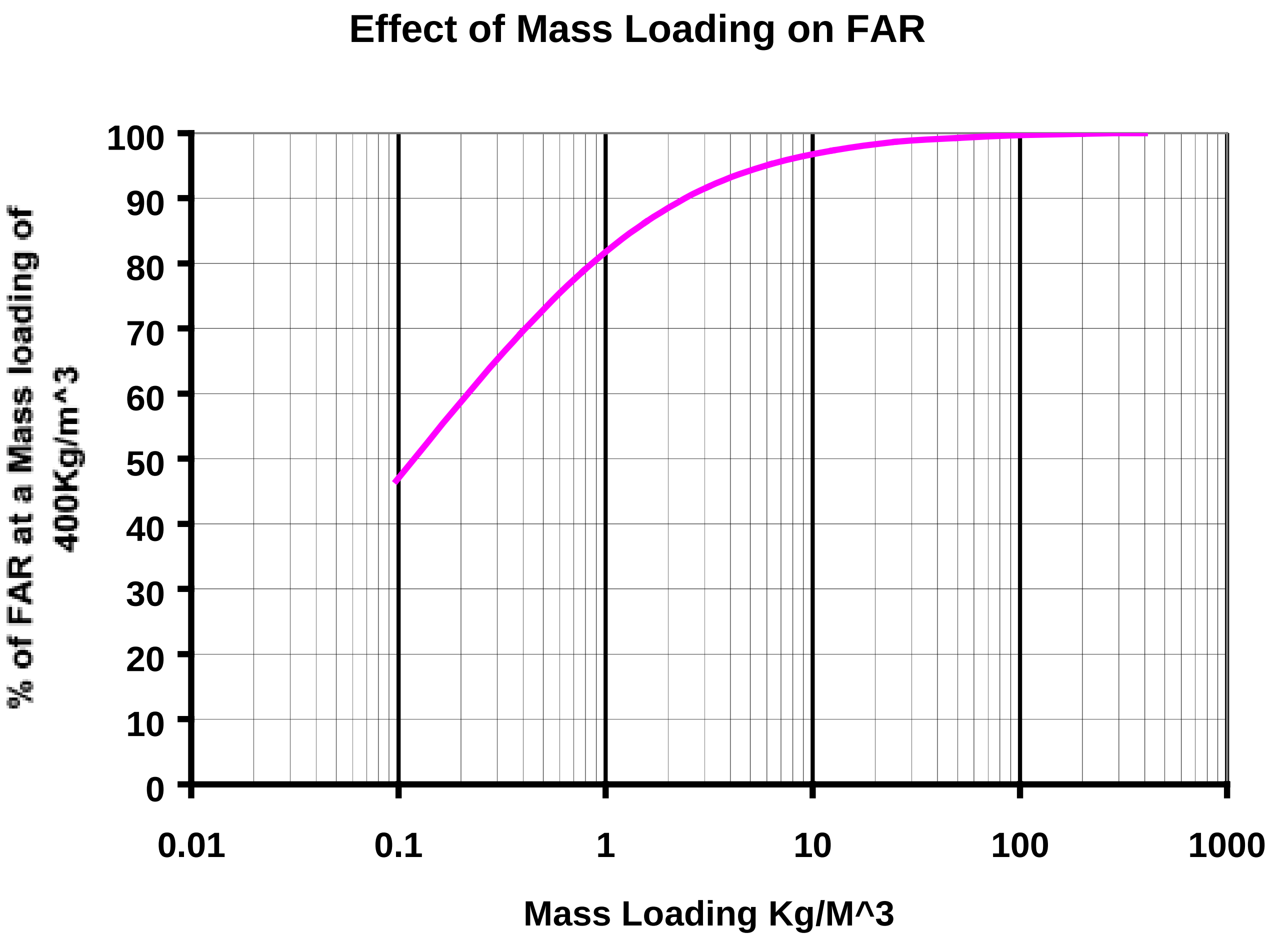

Figure 2: Effects of Mass Loading on Fuel Air Ratio

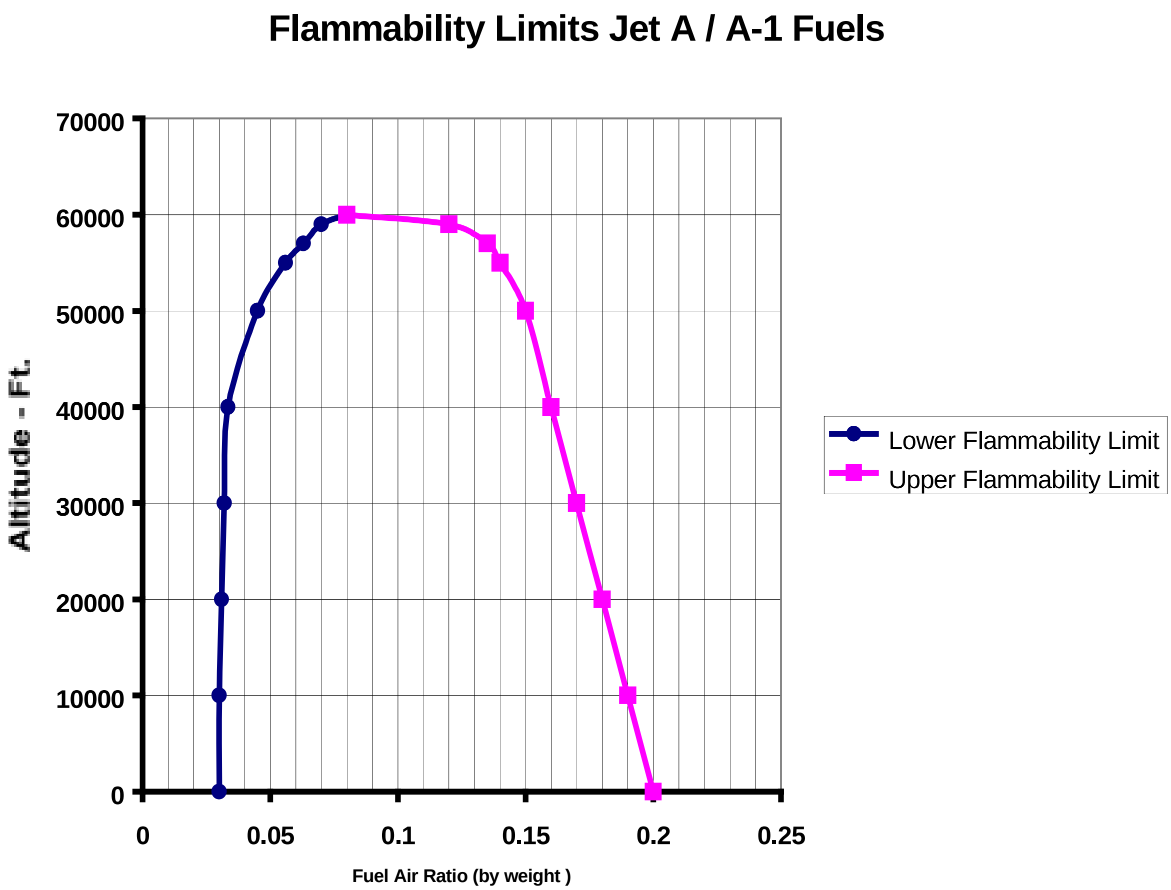

Figure 3: Fuel Vapor Flammability as a Function of Fuel Air Ratio

NOTE: The Flammability limits shown are based on available data and may be updated as research progresses.